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June, 1952

" A Method for Calculating Stresses in Rigid Frame Corners "

by Harvey C. Olander

D i s c u s s i o n

by Lynn S. Beedle *

The development of approximate expressions for predicting the behavior of engineering structures is an important function of engineering research. Usually such expressions are suggested for incorporation into routine design procedures or into specifications. It is important to indicate the range of application of the approximations. If the approximation is on the unsafe side, then it should be demonstrated that the variation was within usual engineering tolerances; if on the safe side, it would likewise be necessary to show that the approximation was not so crude as to be wasteful of material. By comparing his expressions with test results, Mr. Olander has provided much of the information needed.

For those cases in which the number of variables is limited, the most precise analysis could well be the basis for specifications or design procedures. In such instances, tables or graphs may be prepared for engineering use, thereby bringing to bear on each problem the most exact theory available without the necessity for carrying through a detailed computation for each design.

In his interesting paper, Mr. Olander has approached the problem from the first point of view -- the presentation of simple approximate expressions. This is understandable because the corner connection problem contains such a large number of variables. Connections may be straight (a type not treated in the paper but involving direct connection between girder and column), they may involve tapered connections or be of the popular and esthetic type with curved inner flange.

The writer is particularly interested in the stress-analysis of built-up haunches because of the recent development of procedures for plastic analysis and design, a subject being studied at Lehigh University. Referring to the author's Fig 10, his calculations show that first yielding would occur near

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section C-C. (Test results confirm this.) Shortly after yielding at this location, the haunch would buckle due to lateral instability and collapse of the structure would follow.

The advantage, now, of a reasonably accurate method of stress analysis would be to enable the designer to provide a sufficiently strong elastic haunch so that first yielding would occur at section D-D, where the provision of lateral support would be relatively simple, thus more nearly assuring the development of plastic hinges throughout the structure.

These factors are also important from the point of view of design to resist atomic blast loads. Steel structures have sustained overloads effectively because of their ability to absorb energy. Since a haunch which yields is not a particularly good energy-absorber, elastic stress analysis should assist in developing haunches which remain substantially elastic while the rolled shapes joined deform in a plastic manner and allow the frame to absorb energy.

Since Dr. Osgood's work,⁽¹⁾ to which reference has been made by the author, the American Institute of Steel Construction has published two papers with direct bearing on the problem of corner connection design.^(2, 3) In analysing tapered and curved connections, Bleich used circular cross sections and developed a fibre stress equation similar to the " $P/A + Mc/I$ " - type suggested by the author, but containing additional factors to further refine the analysis. A similar situation is true with respect to the problem of shear. Griffiths⁽³⁾ suggests simple rules for the proportioning of straight, tapered, and curved haunches for use in continuous frames.

The next few paragraphs are concerned with the subject of shear. In summarizing, the author states that, "maximum shear stresses are usually at the small sections where the parabolic distribution holds." While possibly true for curved knees, this is not true for straight connections. As has been described elsewhere,⁽⁴⁾ the maximum shear stress in this case is due to the

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- (1) Osgood, Wm. R., "Theory of Flexure for Beams with Nonparallel Extreme Fibres", Trans., A.S.M.E., 1939
 - (2) Bleich, Friedrich, "Design of Rigid Frame Knees", A.I.S.C., July 1943
 - (3) Griffiths, John D., "Single Span Rigid Frames in Steel", A.I.S.C., October, 1948
 - (4) Beedle, Lynn S., Toprac, A.A., and Johnston, Bruce G., "Connections for Welded Continuous Portal Frames", Part II, Welding Journal, August, 1951

transmission of bending stresses at the extreme fibre into shear stresses in the web plating. This situation comes about since the stress at the outside corner must equal zero. It is less serious in the case of the curved haunches due to the larger plate area.

In Fig. 10 of the paper, the maximum exterior flange direct stress is at section C-C. Toward the corner, this stress decreases rapidly, approaching zero at that point. The force represented by this stress is transmitted to the web plating; especially in the case of straight knees, careful consideration must be given to it. (Of course the distribution of shear stress is only parabolic in the case of a rectangular cross section).

Bleich⁽³⁾ has treated shear stresses, suggesting a " VQ/Ib " formula modified by a term which is a function of the bending moment at the section and of the angle β . Since the use of the VQ/Ib expression is only justified in the paper on the basis of two tests, and since the agreement between test and theory is not particularly good, it is considered that further attention should be given to this aspect before the simpler expression is recommended for adoption. It also appears that the term " V " is equal to V_0 and not M_0/r as suggested in the paper.

Concerning bending stresses, the author has probably not mentioned "cross-bending" in curved knee flanges because most of his specimens were of uniform rectangular cross section. As described by Bleich for I-cross-sections,⁽²⁾ due to the compressive force in the inner flange the edges tend to curl in toward the web, thus introducing cross-bending stresses and disturbing the stress distribution across the flange width. The easy-to-remember expression included in the AISC "Rules"⁽³⁾, $b^2/Rt < 2$, controls the relative thickness of flange such that the cross-bending effect is not important. It allows the maximum stress to become no higher than 10% above the nominally computed stress. As stated, the problem does not exist in flat specimens; but in curved connections built up of plate and flange material it must be considered. A few recent tests conducted at the Fritz Engineering Laboratory on large size steel specimens indicate that connections designed by the rules behave satisfactorily.

These rules also require that lateral support be provided at the center of the haunch and at certain other locations. It is further stipulated that web stiffener plates be inserted at points of tangency or of sudden change of slope and at the center of curved haunches. This is consistent with Mr. Olander's recommendations.

In closing this discussion, the author is to be complimented on his presentation which includes both theory and experiment, furnishing to the reader a means of evaluating the recommendations suggested.